ENCODING/DECODING SCHEME TO ACHIEVE STANDARD COMPLIANT MEAN TIME TO FALSE PACKET ACCEPTANCE

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PROBABILITY OF ERROR FOR HARD DECISION DECODING

- **Most hard-decision (HD) decoding of block is bounded distance decoding**
  - BCH and RS codes
  - Berlekamp-Massey decoding algorithm
- **Two kinds outputs for HD decoding**
  - 1) Decoding failure
  - 2) A valid codeword.
- **Output 2) can be a wrong codeword, i.e. not the transmitted codeword**
- **Two kinds of error rates for HD decoding**
  - a) P_f : probability of decoding failure (or uncorrectable)
  - b) P_m : probability of miscorrection (or undetectable)
- **The final probability of error is**

$$P_e = P_f + P_m \text{ (usually } P_f >> P_m\text{)}$$

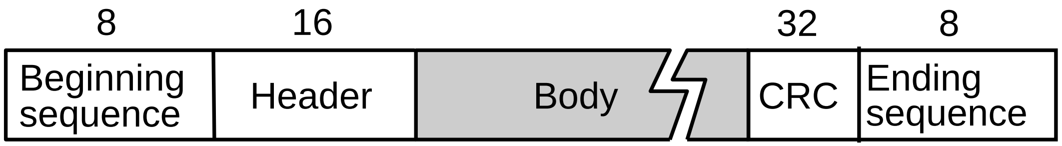
PROBABILITY OF ERROR FOR SOFT DECISION DECODING

- **Optimal decoding: Maximum Likelihood Decoding (MLD)**
  - Always output a codeword
    - The codeword that maximizes the conditional probability of a codeword given a received word
  - No decoding failure for MLD
  - Probability of error is the probability of miscorrection $P_e = P_m$
- **Iterative decoding of LDPC codes**
  - Add a syndrome check for power saving in every iteration
  - Always output a word
    - The decoder will stop iterating if the estimated codeword passes the syndrome check
    - Otherwise it will keep iterating until the maximum number of iterations is reached and output a word
      - The information bits of the output word can be correct even though they may not pass the syndrome check due to errors in the (less protected) parity bits only
      - Therefore the LDPC decoder does not declare a decoding failure in this case
  - Probability of bit error is the probability of miscorrection on information bits

$$P_e = P_{m,\text{info}}$$

PACKET ERROR DETECTION WITH CYCLIC REDUNDANCY CHECK (CRC)

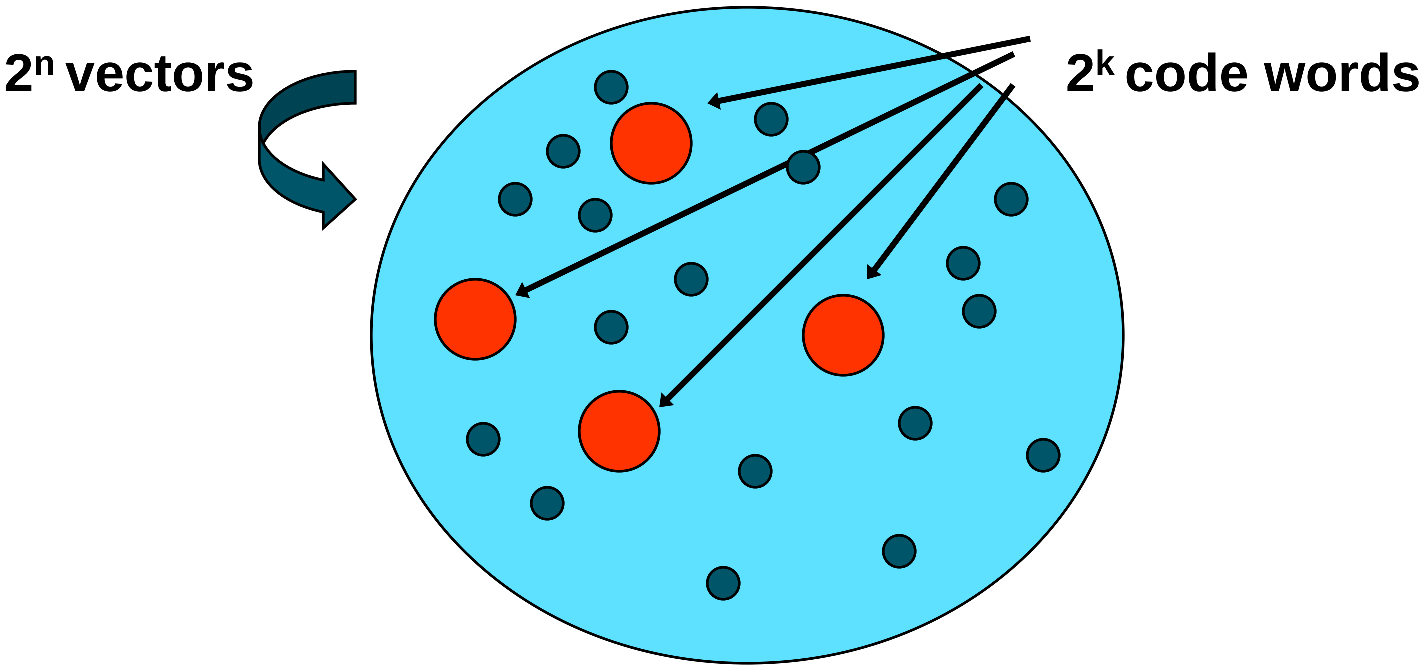
- **Add n-k bits of extra data (the CRC field) to an k-bit message to provide error detection function (i.e. an (n,k) binary cyclic code)**



- **For efficiency, n-k << n**
  - e.g., n-k = 32 for Ethernet and k = 12,000 (1500 bytes)

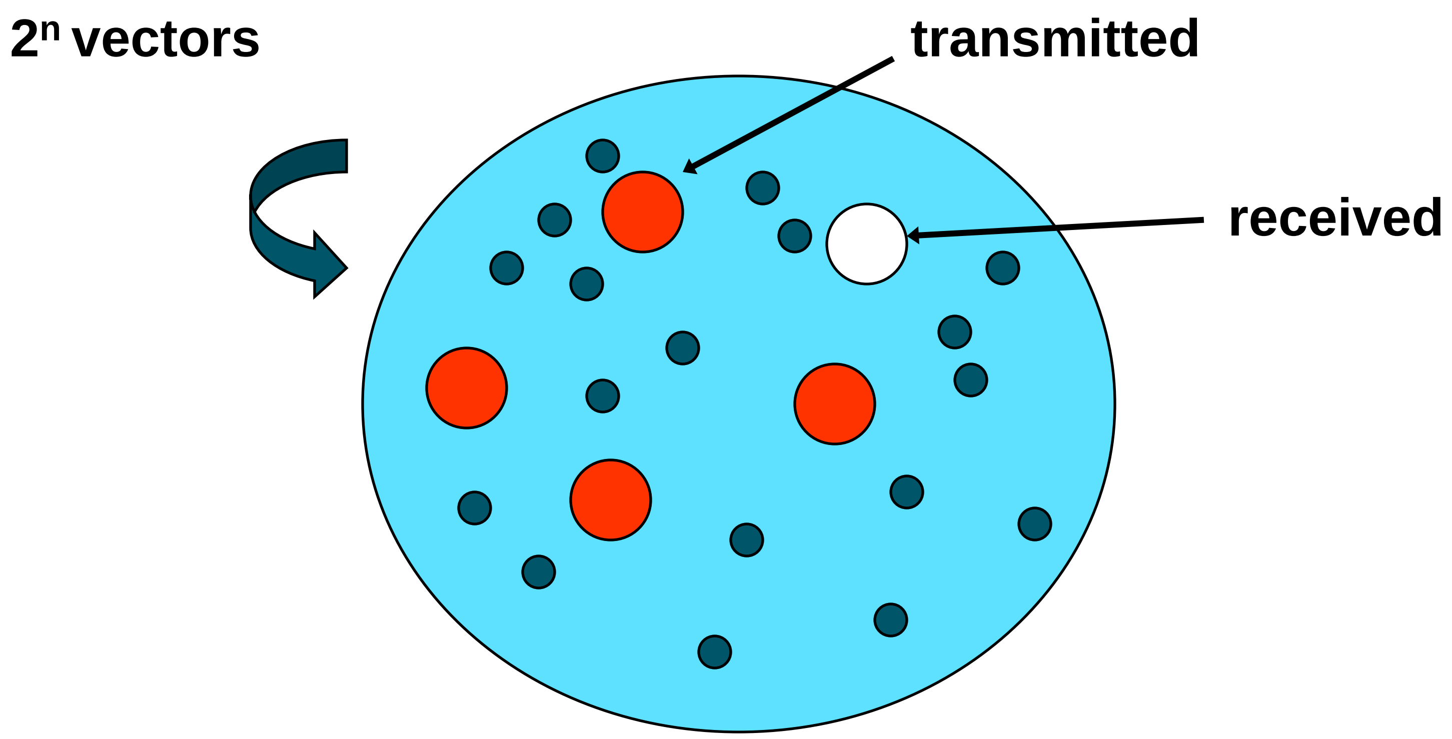
A PICTORIAL VIEW OF CRC CODING

Replace k information bits by a unique n bit code word



ERROR DETECTION

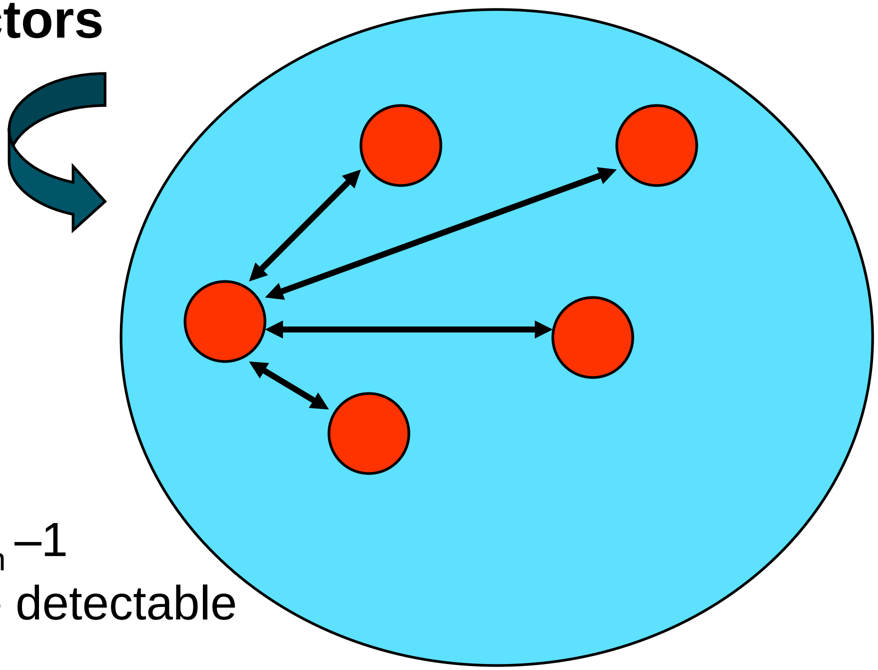
Received vector not equal to one of the 2^k code words



ERROR DETECTION CAPABILITY

code words differ in at least d_{min} positions

2^k vectors



up to $d_{min}-1$
errors are detectable

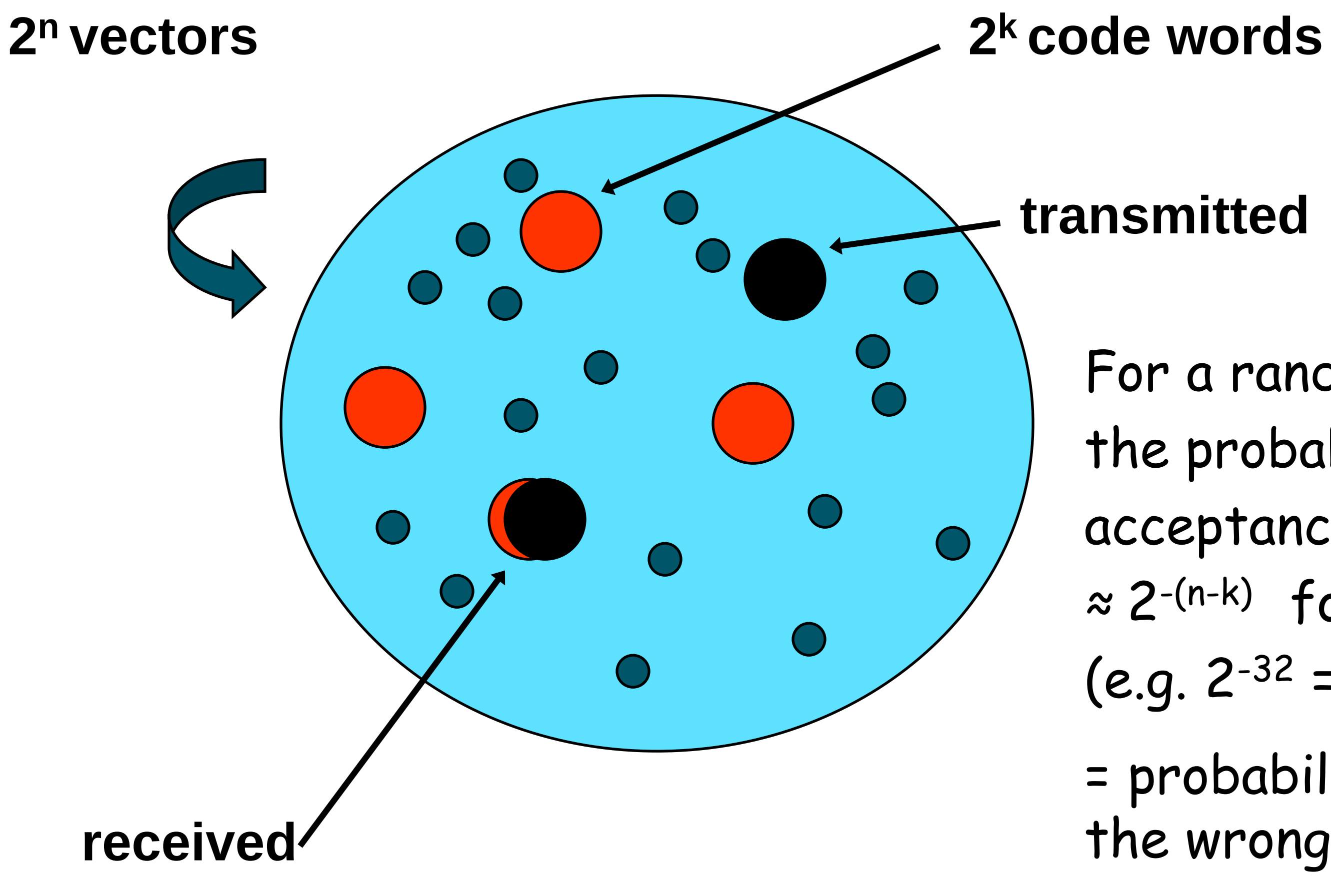
0xx1x0x0

4 differences

1xx0x1x1

$\leq$ 3 errors can be detected

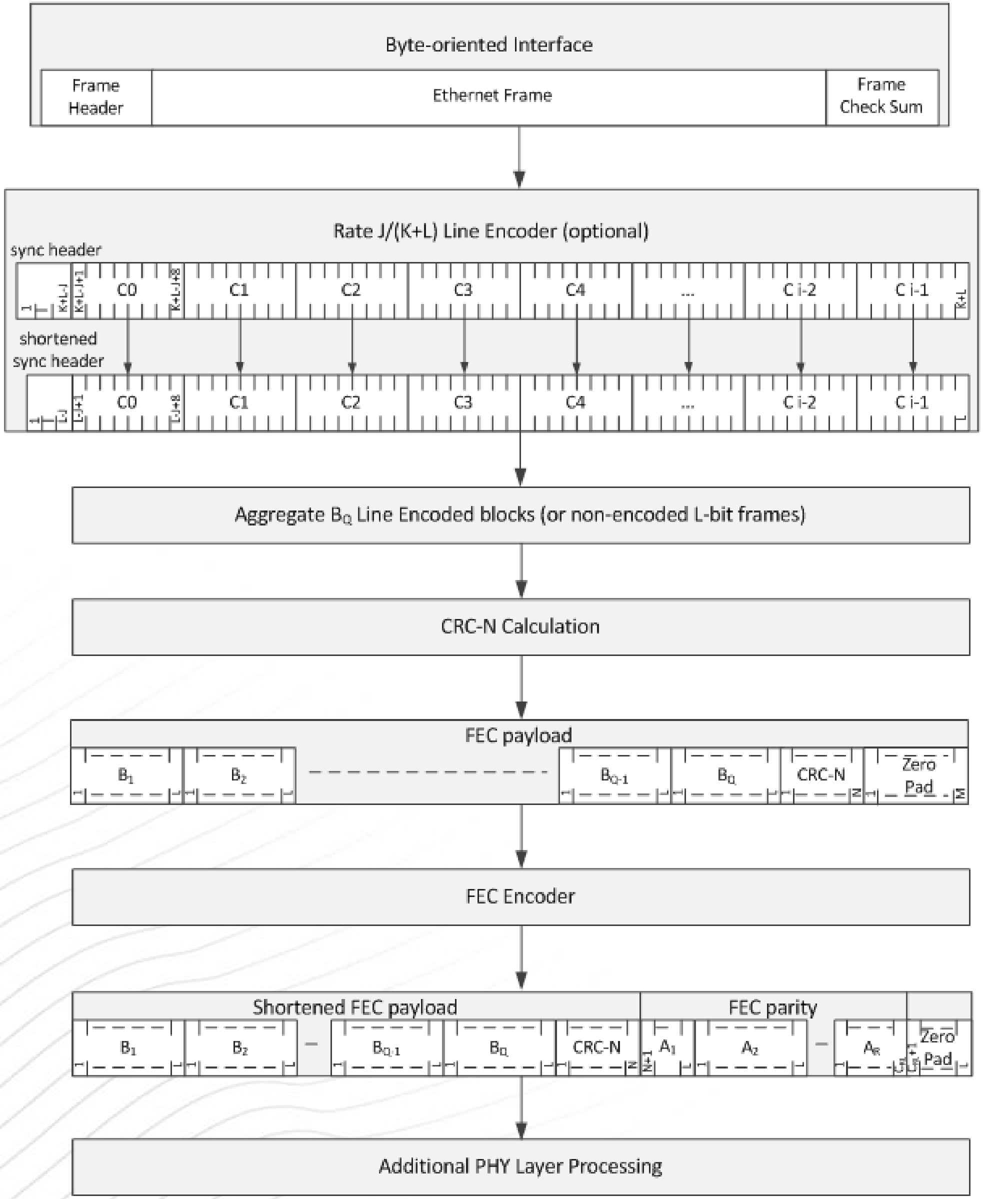
MISDETECTION



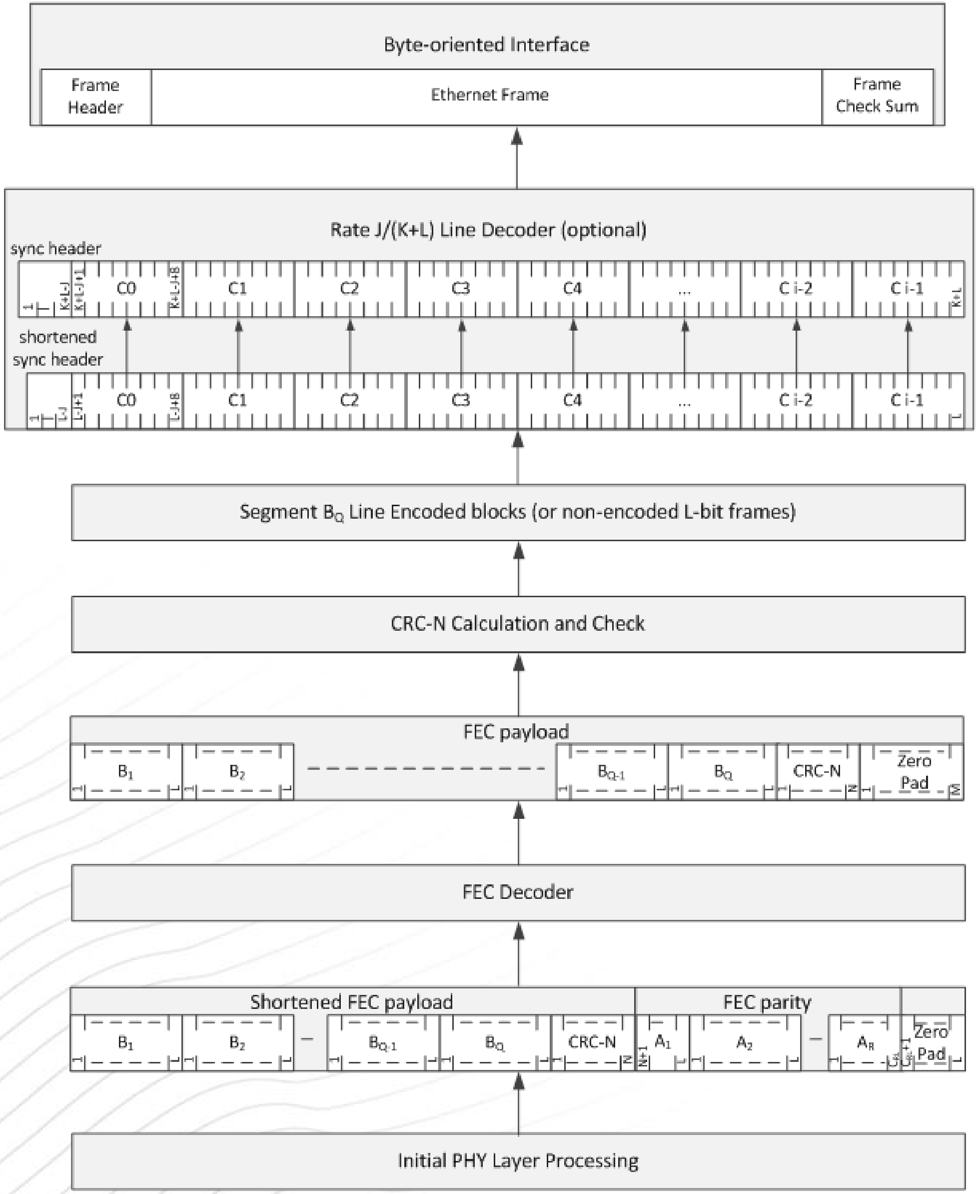
For a random vector:
the probability of false acceptance is $(2^k-1)/2^n \approx 2^{-(n-k)}$ for $2^k \gg 1$
(e.g. $2^{-32} = 2.3e-10$)

= probability of hitting the wrong code word (misdetection)

GENERAL PHY ENCODING SCHEME



GENERAL PHY DECODING SCHEME



FALSE PACKET ACCEPTANCE RATIO

- **For the number of bits N in the CRC plus the number of bits in the FCS (which is 32 for the Ethernet CRC-32 FCS):**

$$FPAR = FLR * F \;/\; 2^{(N+32)}$$

where F is the number of minimum size Ethernet frames including header and FCS per FEC codeword information payload given by:

$$F = \frac{FEC\ Payload}{[8 * (64 + H)]} = \left\lfloor \frac{\lfloor k/L \rfloor}{(64 + H)} * \frac{L}{8} \right\rfloor + \begin{cases} 0, & k \bmod L = 0 \\ 1, & k \bmod L = 1 \\ 2, & k \bmod L \geq 2 \end{cases}$$

and FLR is the Frame Loss Ratio (= Frame Error Ratio).

- **This assumes the worst case where codeword information bit errors corrupt every Ethernet frame in the (n, k) FEC codeword payload.**

FACTORS IN THE CHOICE OF CRC LENGTH

- The length N of the CRC is chosen to be long enough to insure the MTTFPA is achieved.
- The MTTFPA is the inverse of the False Packet Acceptance Ratio (FPAR) times the Ethernet frame bit rate R:

$$MTTFPA = 1/(FPAR * R)$$

- The minimum MTTFPA occurs at the maximum packet rate since they are inversely related.
- For a fixed bit rate B over the PHY layer, the packet rate is maximized for the smallest size Ethernet frames (64 bytes plus any additional header):

$$R = \frac{B}{8 * (64 + H + IFG)}$$

- where the number of header bytes H plus the number of bytes for the inter-frame gap IFG are added to the minimum Ethernet payload size of 64 bytes.

MEAN TIME TO FALSE PACKET ACCEPTANCE

- **Therefore the MTTFPA which is the inverse of the FPAR times the Ethernet frame rate R is given by:**

$$MTTFPA = 1/(FPAR * R) = 1/\left(FLR * F * 2^{-(N+32)} * \frac{B}{8 * (64 + H + IFG)}\right)$$

- **So the minimum value N for a CRC to achieve a desired MTTFPA can be calculated solving for N above:**

$$N \geq \frac{\log\left[MTTFPA * FLR * F * \frac{B}{8 * (64 + H + IFG)} * 2^{-32}\right]}{\log[2]}$$

- **The preferred value of the MTTFPA in IEEE 802.3 standards is the age of the universe which is estimated to be 14 billion years (4.4×10^{17} seconds).**

EPOC CRC LENGTH (DOWNSTREAM)

The number of minimum size Ethernet frames including header and FCS per long FEC codeword information payload given by:

$$F = \left\lfloor \frac{\lfloor 14400/65 \rfloor}{(64+8)} * \frac{65}{8} \right\rfloor + 2 = 26$$

- **For an FLR of 1e-6 in the downstream at a 10 Gbps bit rate,**

$$N \geq \frac{\log\left[4.4 \text{ x } 10^{17} * 10^{-6} * 26 * \frac{10 \text{ x } 10^{9}}{8 * (64+8+12)} * 2^{-32}\right]}{\log[2]} = 35.2$$

- **A minimum 36 bit CRC is needed to achieve the required MTTFPA**
- **Choose a standard 40 bit CRC used in GSM control channels (with a FIRE code for FEC)**
  - CRC generator polynomial $x^{40} + x^{26} + x^{23} + x^{17} + x^{3} + 1$

EPOC MEAN TIME TO FALSE PACKET ACCEPTANCE (DOWNSTREAM)

- **For a 40 bit CRC plus the 32 bits in the FCS, the Mean Time To False Packet Acceptance is:**

$$MTTFPA = 1/\left(10^{-6} * 26 * 2^{-(40+32)} * \frac{10 \text{ x } 10^{9}}{8 * (64 + 8 + 12)}\right) = 1.22 \text{ x } 10^{19}$$

- **This is greater than the required age of the universe MTTFPA of 4.4×10^{17} seconds.**

EPOC MEAN TIME TO FALSE PACKET ACCEPTANCE (UPSTREAM)

- **For the same 40 bit CRC plus the 32 bits in the FCS, the Mean Time To False Packet Acceptance is:**

$$MTTFPA = 1/\left(5 \text{ x } 10^{-5} * 26 * 2^{-(40+32)} * \frac{10 \text{ x } 10^{9}}{8 * (64 + 8 + 12)}\right) = 2.44 \text{ x } 10^{17}$$

- **This is less than the required age of the universe MTTFPA of $4.4 \text{ x } 10^{17}$ seconds.**

- **Approaches to increase the upstream MTTFPA**
  - Use a longer CRC
  - Reduce the Frame Loss Ratio
  - Reduce the maximum PHY layer bit rate

- **Best approach is to reduce the upstream bit rate**

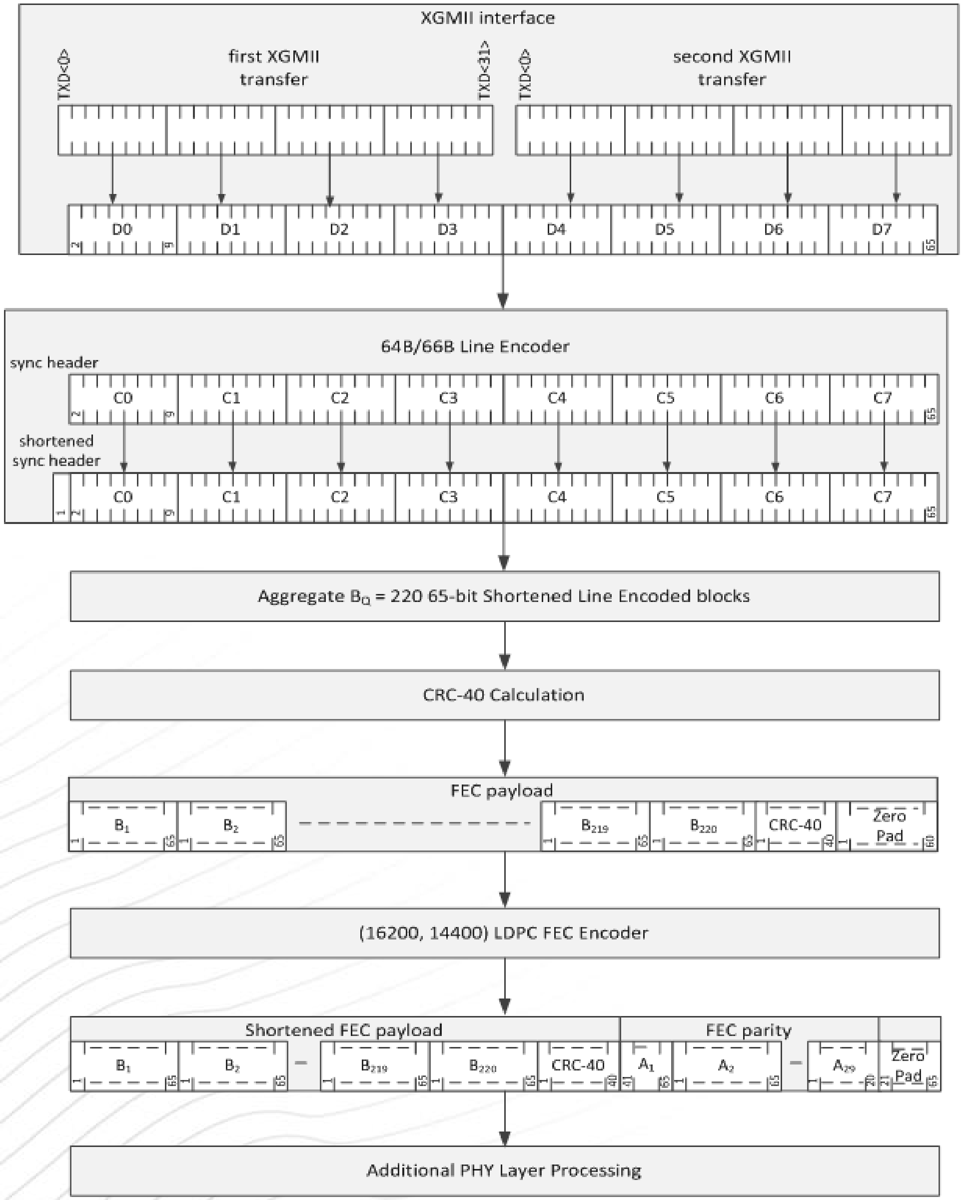
EPOC MEAN TIME TO FALSE PACKET ACCEPTANCE (UPSTREAM) - CONTINUED

- **Reduce the upstream maximum PHY layer bit rate to 5 Gbps**
- **For the same 40 bit CRC plus the 32 bits in the FCS, the Mean Time To False Packet Acceptance is:**

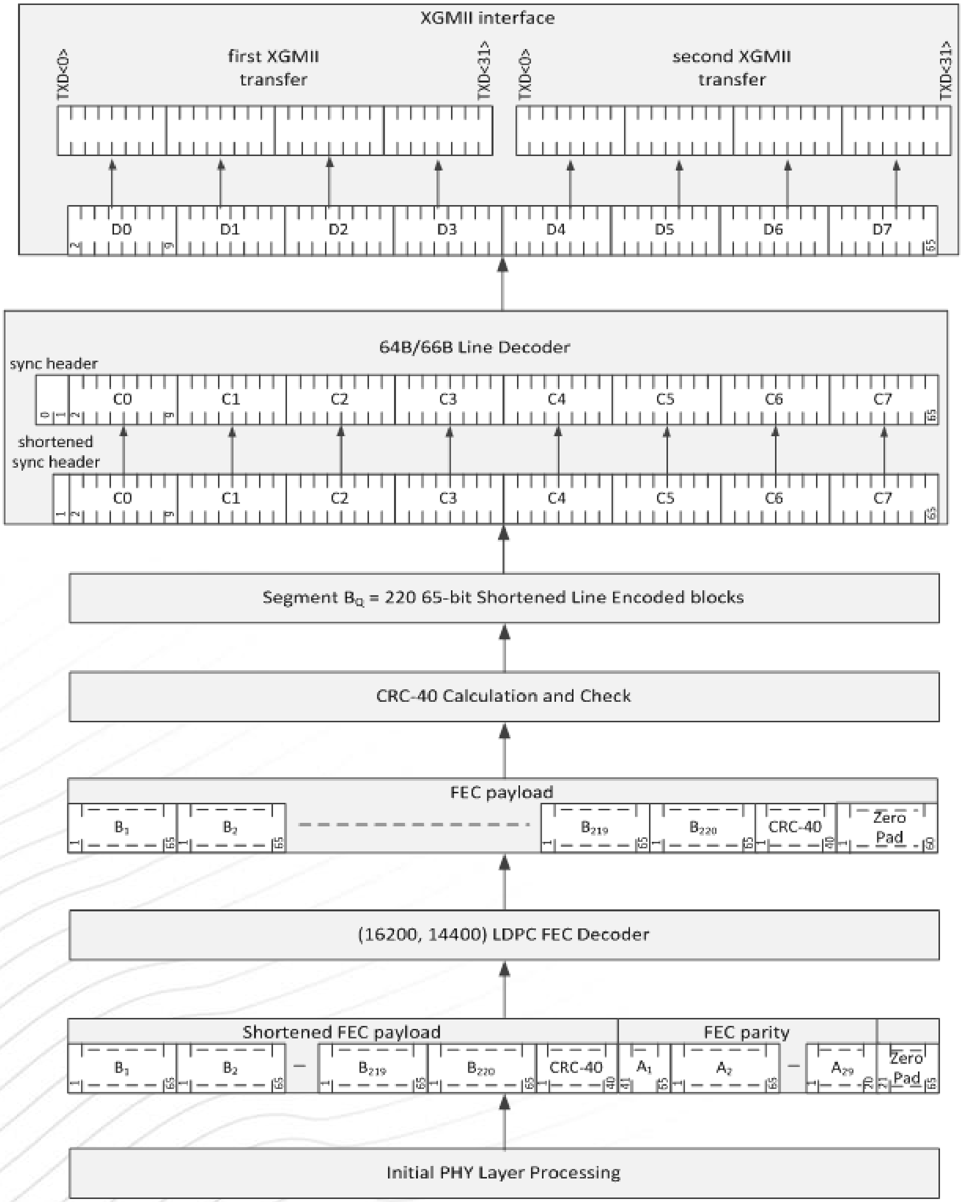
$$MTTFPA = 1/\left(5 \text{ x } 10^{-5} * 26 * 2^{-(40+32)} * \frac{5 \text{ x } 10^{9}}{8 * (64 + 8 + 12)}\right) = 4.88 \text{ x } 10^{17}$$

- **This is now greater than the required age of the universe MTTFPA of 4.4 x 10^{17} seconds.**

EPOC PHY ENCODING SCHEME



EPOC PHY DECODING SCHEME



65B TO 64B/66B EXPANSION AT RECEIVER

- **For each FEC Payload received (or equivalent)**
  (Similar to 74.7.4.5 FEC decoder)

  - If Information CRC check is good
    - For each block contained in B_Q:
      - Set Bit 0 of expanded 64b/66b Sync Header to inverse of 65b Bit 0 (XOR)
      - Append remaining 65 bits from block
  - If Information CRC check is bad
    - For every block contained in B_Q:
      - Set Bit 0 and Bit 1 of expanded 64b/66b Sync Header to ‘11’ to indicate invalid
      - Discard Bit 0 of 65b block
      - Append remaining 64 bits of 65b block

- **Higher layer 64b/66b decoding will process as normal**
  - A “invalid” Sync Header gets flagged as “sh_invalid” and processed/counted accordingly to ensure that detected errors are signaled to the MAC for every frame containing an error.

CONCLUSION

- **An encoding and decoding scheme to achieve standard compliant Mean Time to False Packet Acceptance has been presented**
- **Analysis of this approach utilizing a 40 bit CRC exceeds the required MTTFPA equal to the age of the universe**
- **The use of a standardized 40 bit CRC used in the GSM standard is proposed for this scheme**
- **The maximum bit rates for the PHY layer depend on the Ethernet Frame Loss Ratios**
  - 10 Gbps downstream with a 1e-6 Frame Loss Ratio
  - 5 Gbps upstream with a 5e-5 Frame Loss Ratio

MOTION PROPOSAL

Move to:

Incorporate the MTTFPA encoding/decoding scheme as presented in prodan_3bn_02_0913.pdf with the adopted FEC codes in the downstream and upstream EPoC PHY layer.

Moved:

Second:

Technical decision, 75% or greater

Yes:

No:

Abstain:

Thank You